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BRIEF COMMUNICATION

Parasagittal Cystic Lesions May Arise from the Pial Sheath around the Cortical Venous Wall

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It has been reported that perivenous cystic structures near the parasagittal dura are associated with the leakage of gadolinium-based contrast agents at 4 hours after intravenous administration. The origin of such cystic structures remains unknown. While reading many cases of MR cisternography, we noticed that some of the cystic structures appeared to connect to the perivenous subpial space. This new imaging finding might facilitate future research of the waste clearance system for the central nervous system.

Keywords: *cyst, glymphatic, magnetic resonance imaging, parasagittal dura*

In the vicinity of the superior sagittal sinus, there are structures that constitute the downstream portion of the glymphatic system, including the meningeal lymphatics and parasagittal dura, which have been the subject of extensive anatomical and MR imaging research in recent years.[1–4] Various reports have analyzed the distribution of intravenously administered gadolinium-based contrast agents (GBCAs) in the subarachnoid space using 3D-real inversion recovery (IR) imaging, which can detect low concentrations of GBCAs in fluids.[5,6] The 3D-real IR images obtained at 5–10 mins after intravenous GBCA administration showed a line-shaped contrast distribution along the periphery of the cortical veins on the brain surface.[7,8] It is presumed that this finding depicts a slight GBCA leakage through an impaired blood-brain barrier into the brain parenchyma, and drainage into the subpial space around the cortical veins via the glymphatic system.[1] Furthermore, it has been reported that cyst-like structures are often seen near bridging and cortical veins in the parasagittal region on 3D-real IR obtained at 4 hours after intravenous GBCA administration.[6,9] Imaging findings, such as remodeling of the inner table of the skull and compression of the brain parenchyma due to such cyst-like structures, have also been reported.[6]

Cystic structures are more frequent in patients with GBCA leakage from the subpial space around the cortical veins into the subarachnoid space at 4 hours after intravenous GBCA administration than in patients without leakage.[6] Other reports indicated that leakage of GBCA into the subarachnoid space was associated with aging and was more pronounced above the age of 37 years.[7,10] Although the number of cyst-like structures did not correlate with age, the size was greater in subjects with GBCA leakage into the subarachnoid space, and also the size tended to increase with age.[6] This suggests that these cyst-like structures might be congenital, rather than acquired. When observed serially over time after intravenous GBCA administration, the GBCA inside the cyst-like structures remained longer in cases with leakage into the subarachnoid space, than in cases without.[9] These cyst-like structures have also been detected by MR cisternography, suggesting that cysts adjacent to the bridging and cortical veins are associated with leakage of intravenously administered GBCA into the subarachnoid space.[11]

Studies using contrast-enhanced methods,[8] and non-contrast-enhanced methods[12], have reported that the subpial space around the cortical veins functions as a drainage pathway for cerebral interstitial fluid and is continuous with the meningeal lymphatics near the superior sagittal sinus. It has been postulated that these cystic structures may be associated with the interstitial fluid through the subpial spaces around the veins.[1]

We have noticed that in many cases of MR cisternography, when looking at cysts in the parasagittal region, there are often morphologic features, which suggest that the cyst is associated with the interstitial fluid through the perivenous subpial spaces. The purpose of this article is to show representative images of this finding and to provide an opportunity for

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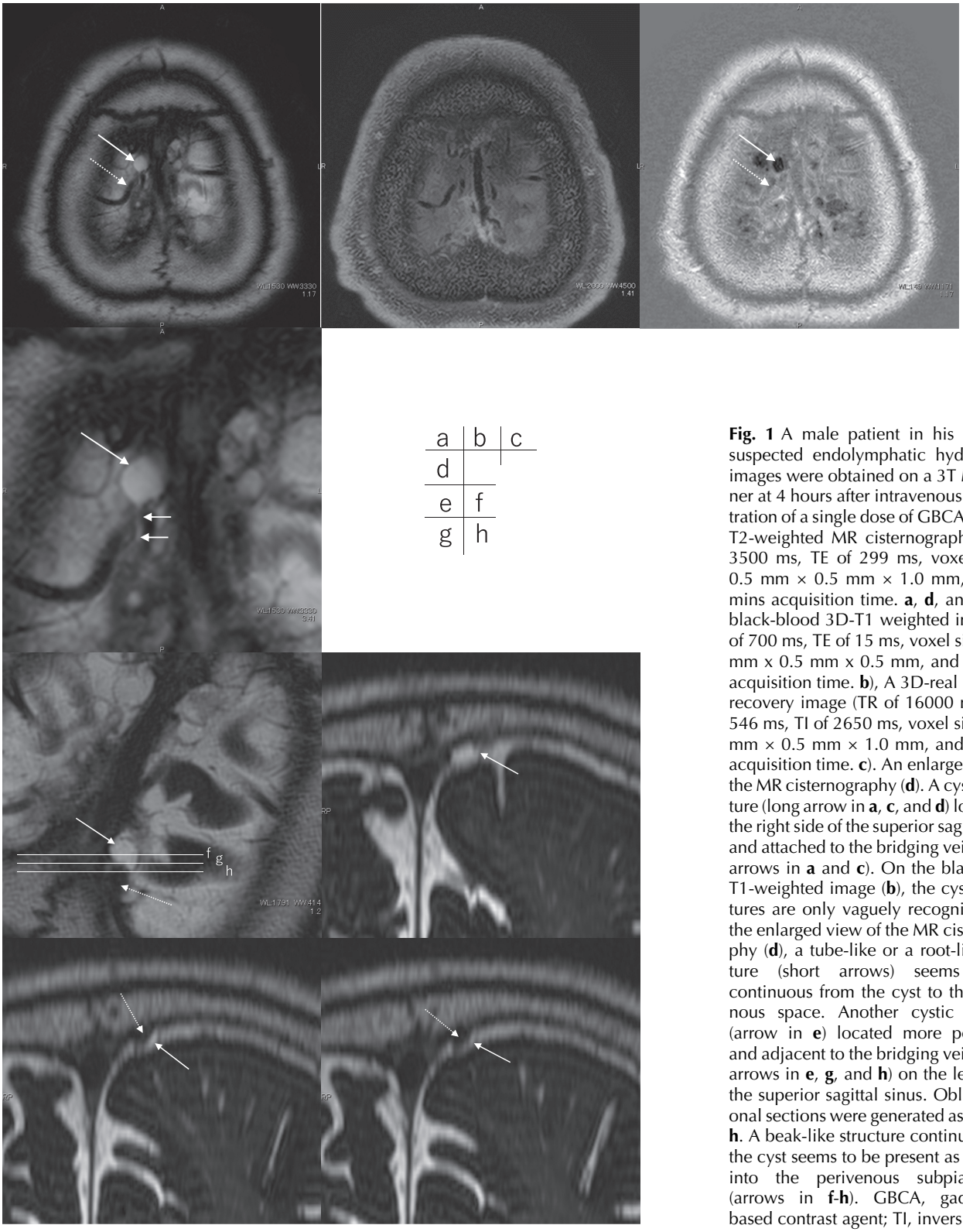

Fig. 1 A male patient in his 70s with suspected endolymphatic hydrops. All images were obtained on a 3T MR scanner at 4 hours after intravenous administration of a single dose of GBCA. Heavily T2-weighted MR cisternography (TR of 3500 ms, TE of 299 ms, voxel size of 0.5 mm × 0.5 mm × 1.0 mm, and 4.8 mins acquisition time. **a**, **d**, and **e**-**h**), A black-blood 3D-T1 weighted image (TR of 700 ms, TE of 15 ms, voxel size of 0.5 mm x 0.5 mm x 0.5 mm, and 4.9 mins acquisition time. **b**), A 3D-real inversion recovery image (TR of 16000 ms, TE of 546 ms, TI of 2650 ms, voxel size of 0.5 mm × 0.5 mm × 1.0 mm, and 10 mins acquisition time. **c**). An enlarged view of the MR cisternography (**d**). A cystic structure (long arrow in **a**, **c**, and **d**) located on the right side of the superior sagittal sinus and attached to the bridging vein (dotted arrows in **a** and **c**). On the black-blood T1-weighted image (**b**), the cystic structures are only vaguely recognizable. In the enlarged view of the MR cisternography (**d**), a tube-like or a root-like structure (short arrows) seems to be continuous from the cyst to the perivenous space. Another cystic structure (arrow in **e**) located more posteriorly and adjacent to the bridging vein (dotted arrows in **e**, **g**, and **h**) on the left side of the superior sagittal sinus. Oblique coronal sections were generated as shown **f**-**h**. A beak-like structure continuous with the cyst seems to be present as it transits into the perivenous subpial space (arrows in **f**-**h**). GBCA, gadolinium-based contrast agent; TI, inversion time.

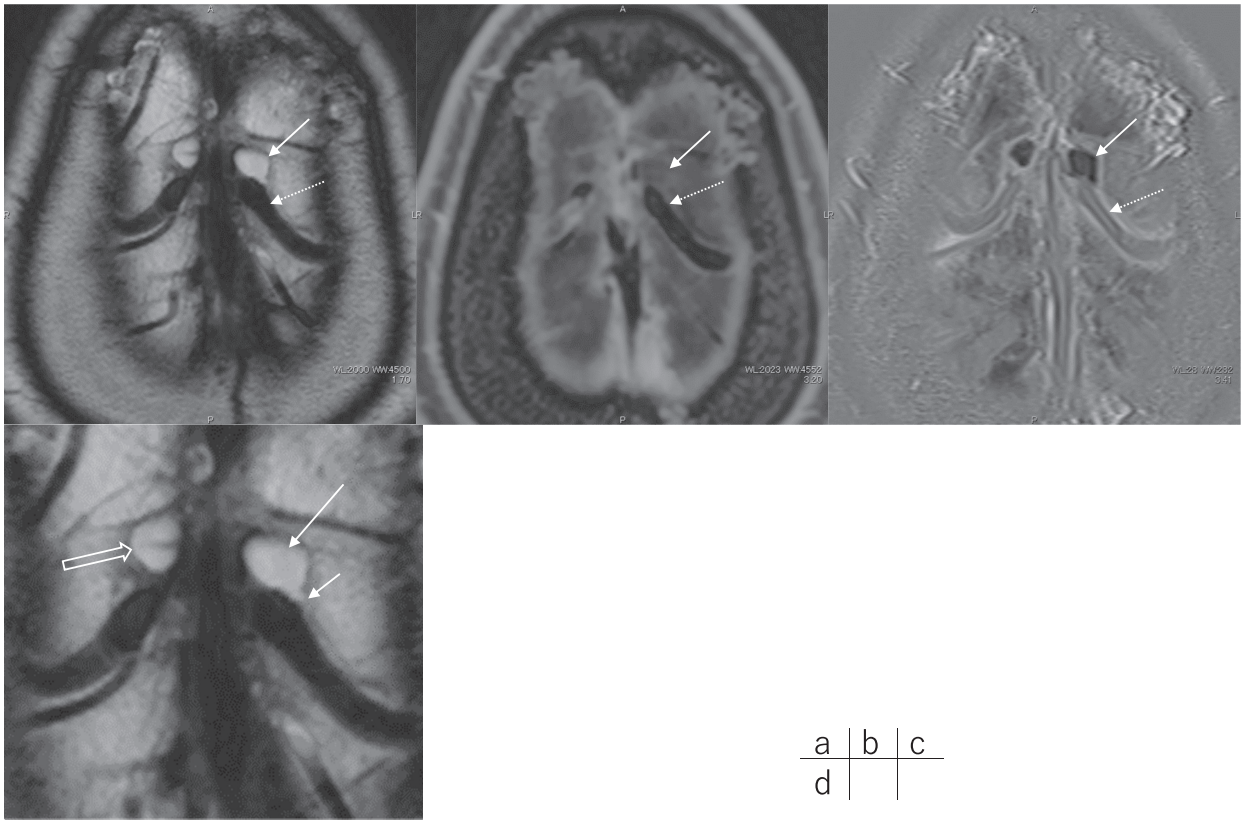

Fig. 2 A male patient in his 60s with suspected endolymphatic hydrops. All images were obtained on a 3T MR scanner at 4 hours after intravenous administration of a single dose of GBCA. Heavily T2-weighted MR cisternography (**a**). A black-blood 3D-T1-weighted image (**b**). A 3D-real inversion recovery image (**c**). An enlarged view of the MR cisternography (**d**). The scan parameters are the same as those used for Fig. 1. A cystic structure (long arrow in **a**, **c**, and **d**) located on the left side of the superior sagittal sinus and attached to the bridging vein (dotted arrow in **a**-**c**). On the black-blood T1-weighted image, the cystic structure is only vaguely recognizable (arrow in **b**). A beak-like structure (short arrow in **d**) seems to be continuous from the cyst to the perivenous space. Another cystic structure (open arrow in **d**) is seen on the right side of the superior sagittal sinus and attached to the bridging vein. The symmetric presence of the cystic structures makes us speculate that these cystic structures might not be a result of arachnoiditis, but rather might have grown from the pre-existing structures. GBCA, gadolinium-based contrast agent.

further research in the neuroscience and neuroradiology communities of these cystic structures in the parasagittal region. We are currently performing whole brain heavily T2-weighted MR cisternography, black-blood 3D-T1-weighted imaging, and 3D-real inversion recovery imaging at 4 hours after intravenous administration of a single dose of GBCA for the MR examination of endolymphatic hydrops.

In the two cases shown in Figs. 1 and 2, the leakage of GBCA into the subarachnoid space around the cortical veins was confirmed by 3D-real IR imaging. In addition, the cyst-like structures near the bridging veins in the parasagittal region can be seen in the heavily T2-weighted MR cisternography and 3D-real inversion recovery images (Fig. 1, 2). A detailed examination of these cysts reveals morphological features on heavily T2-weighted MR cisternography, which suggests the site of origin for the cysts. The tube-like or beak-like projections extend from the cysts to the perivenous space. In such cases, we, sometimes, see the cystic structures located symmetrically on both sides of the superior sagittal sinus (Fig. 2). This symmetric property makes us hypothesize that these cystic structures are congenital rather than acquired inflammation.

At the site where the bridging vein enters the superior sagittal sinus, arachnoid granulations are often present.[4,13] There are numerous arachnoid granulations in the parasagittal dura.[2,4] According to a recent anatomical report, two subtypes of arachnoid granulations can be found in the parasagittal area, which include intradural and interdural subtypes. The intradural subtype arachnoid granulation drains into the tubular channel with both vascular and lymphoid markers, then into the venous lacunae, and finally to the superior sagittal sinus. Part of the interdural subtype directly drains into the superior sagittal sinus, suggesting that arachnoid granulations play a role in the central nervous system similar to that of lymph nodes in the periphery.[4] The parasagittal dura contains many arachnoid granulations, and a fluid-filled cavity that acts as a channel is present. Research has indicated that after GBCA is administered into the

intrathecal space, it is absorbed into the parasagittal dura,[2] which includes the meningeal lymphatics. The meningeal lymphatics have been visualized in humans by MR imaging.[3] The parasagittal dura, also known as the peri-sinus lymphatic space, increases in volume with age.[14] In an animal study, the size of the perivascular space around the cortical veins changes dynamically according to mechanical stimulation of the brain parenchyma.[15]

Taken together, these findings suggest that the parasagittal dura exists downstream of the glymphatic system and functions as a kind of organ, which absorbs various molecules from the cerebrospinal fluid (CSF) into the subarachnoid space and distributes fluids and various molecules to the lymphatic and bloodstream systems. Research in this area is still active, and it was recently reported that the absorption of GBCA into the CSF in the parasagittal dura is not affected by sleep.[16]

Based on the characteristic imaging findings in this paper, cysts in the parasagittal region are present amidst the interstitial fluid drainage, suggesting that they are arachnoid granulation-related retention cysts. However, there is still a lack of detailed anatomical and functional knowledge about the relationship between the parasagittal dura and its surrounding structures. Histological analyses of these cyst-like structures are definitely necessary in the future. However, it might be technically challenging to acquire the histological specimens while preserving the delicate details of these cystic structures. For MR imaging analysis, there are several questions to be answered. How often do we see the cyst-like structures with tube-like or beak-like projections? Do the cysts sometimes rupture? Are there diurnal variations in the cysts? How does a cyst change over time with aging? Are the size and content of the cystic structures related to sleep? Are they associated with specific diseases or neurological findings? Do they change with any therapeutic interventions?

As indicated in this present article, these cystic structures can be visualized on MR cisternography. It is expected that this report will encourage research of these cyst-like structures in many institutions to answer the above-mentioned questions.

Conflicts of Interest

Toshiaki Taoka and Rintaro Ito are professors in the Department of Innovative Biomedical Visualization (iBMV), which is financially supported by CANON MEDICAL SYSTEMS CORPORATION.

All other authors declare that they have no conflicts of interest regarding this manuscript.

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